Development of fiber-based laser systems for LISA

Kenji Numata, Jordan Camp

Abstract

We present efforts on fiber-based laser systems for the LISA mission at the NASA Goddard Space Flight Center. A fiber-based system has the advantage of higher robustness against external disturbances and easier implementation of redundancies. For a master oscillator, we are developing a ring fiber laser and evaluating two commercial products, a DBR linear fiber laser and a planar-waveguide external cavity diode laser. They all have comparable performance to a traditional NPRO at LISA band. We are also performing reliability tests of a 2-W Yb fiber amplifier and radiation tests of fiber laser/amplifier components. We describe our progress to date and discuss the path to a working LISA laser system design.

LISA

Beyond Einstein: From the Big Bang to Black Holes

Development of fiber-based laser systems for LISA

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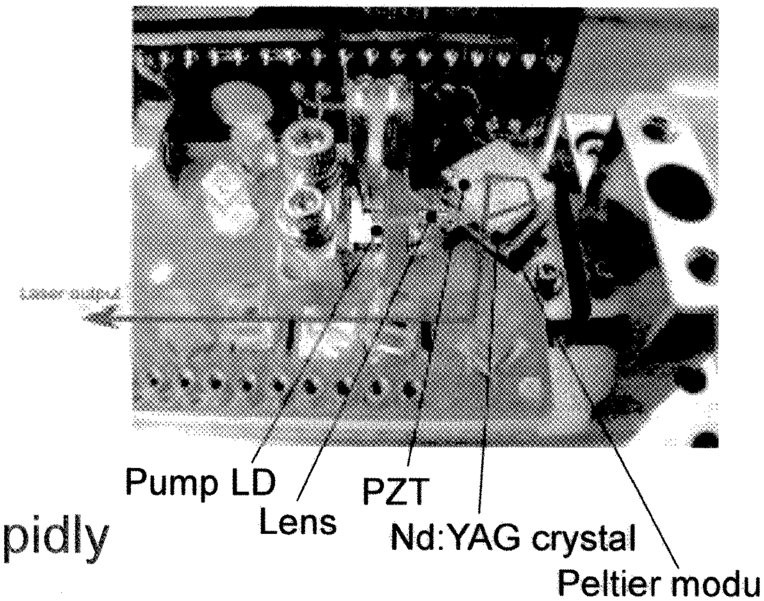
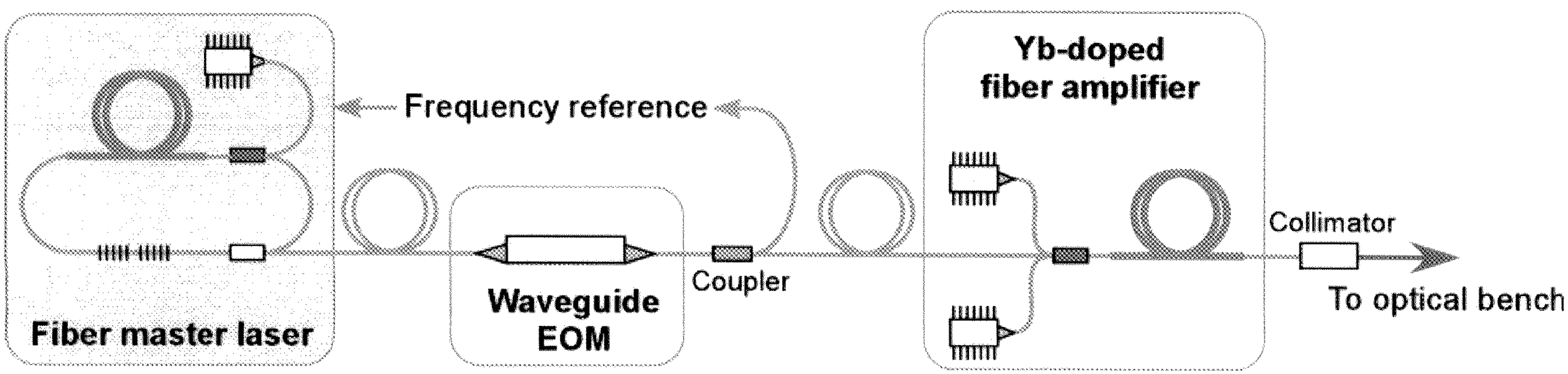
Contents

1. Introduction

- NPRO (Non-planar ring oscillator) has been used traditionally.
  - Compact crystal cavity gives high stability.
  - "Black box" in many cases
    - E.g.) TESAT NPRO for LPF

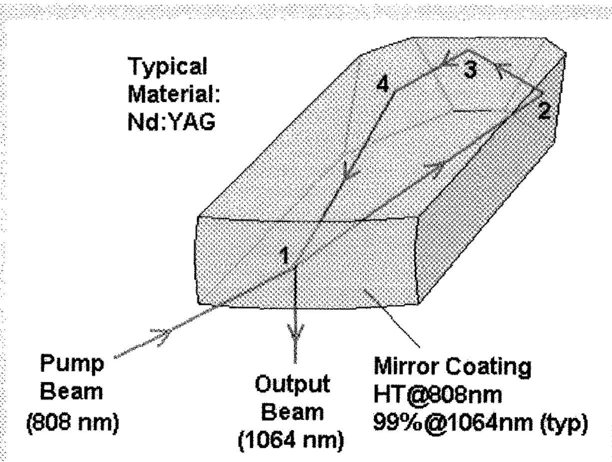
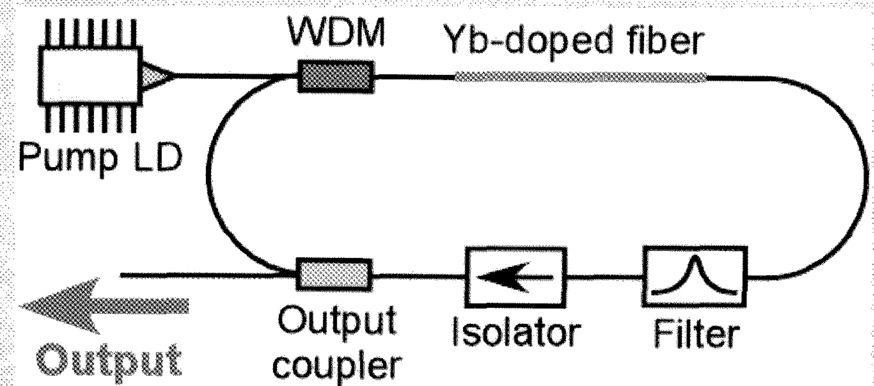


- All fiber/waveguide solution
  - Fiber laser/amplifier technologies matured rapidly
  - Higher robustness



NPRO vs fiber laser

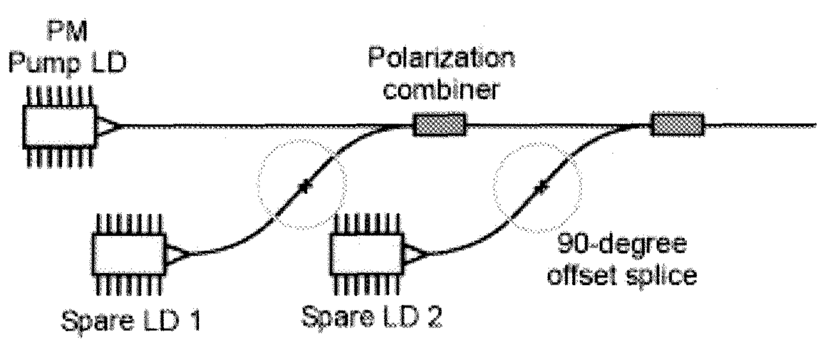
- Fiber laser offers significant advantages over NPRO laser

Traditional: NPRO laser	New: Fiber laser
	
Difficult alignment	**No alignment needed**
Glue/solder needed	**No glue needed**
Need to couple back into fiber	**Laser light within fiber**
Strong magnet needed	**No strong magnet**
Contamination sensitive (sealed package)	**No contamination**
Distorted Gaussian beam	**Mode & polarization cleaned by fiber**

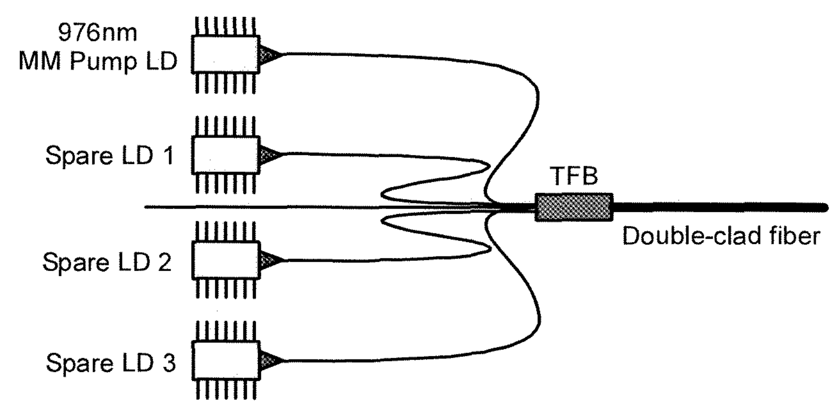
Solid-state amp vs fiber amp

- Fiber amp has..
  - Higher beam quality, lower sensitivity to alignment etc., easier cooling
  - Higher reliability, **higher optical/wallplug efficiency**
    - E.g. Commercial fiber amp: >10% wallplug efficiency
    - ~2% efficiency in solid state amps in flight missions

- Easier addition of redundancy
  - Many (~90%?) laser failures come from pump LD
  - No geometrical constraints



▪Core pumping by SM LDs



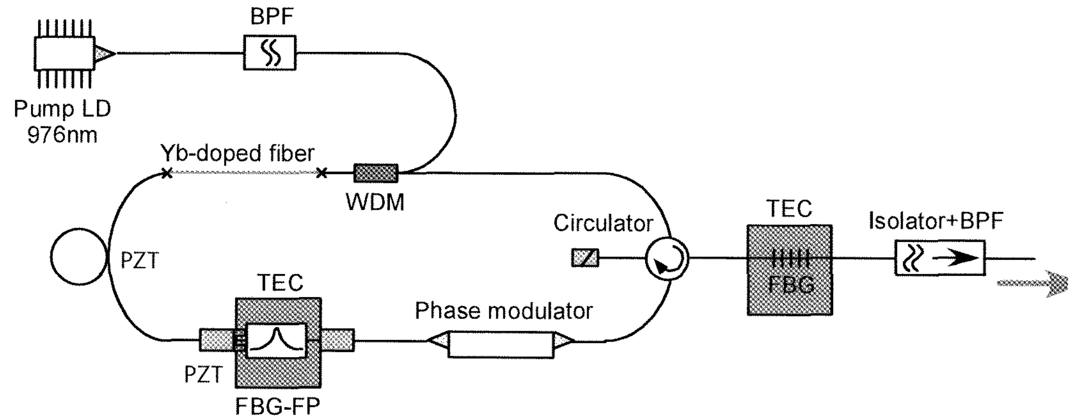
▪Clad pumping by MM LDs

2. Fiber-based lasers

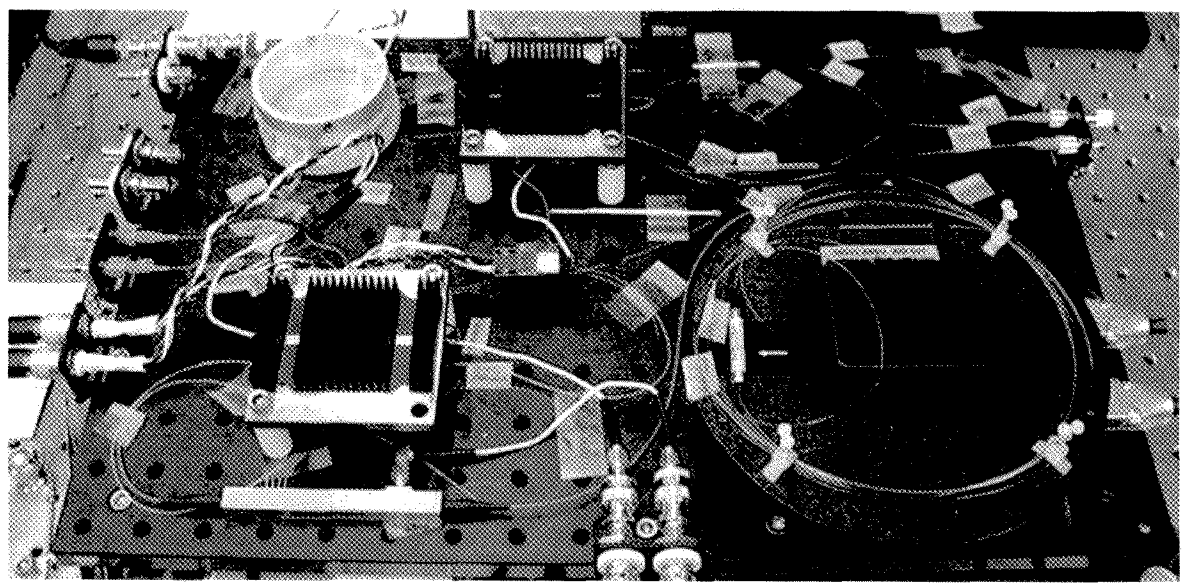
- GSFC fiber ring laser
  - Commercial highly-doped gain fiber + fiber Bragg gratings
- NP photnics/Fibertek DBR fiber laser
  - Special phosphosilicate glass fiber + fiber Bragg gratings
- RIO external cavity diode laser (ECL)
  - InP semiconductor gain chip + planar-waveguide Bragg reflector

GSFC fiber ring laser

- Features
  - Design & built in house
  - Commercial components only
    - No special gain fiber
    - No patent issues
  - Two FBGs for single-mode selection
  - Fast frequency tuning by waveguide EOM
  - Low power (~2mW)

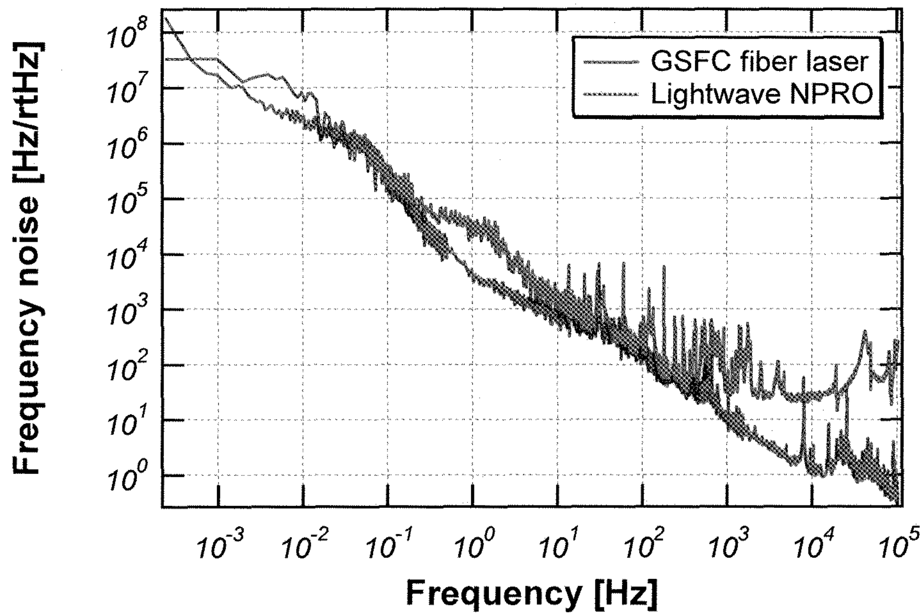


- Status
  - Design fixed
  - Iodine stabilization
  - Digital system design

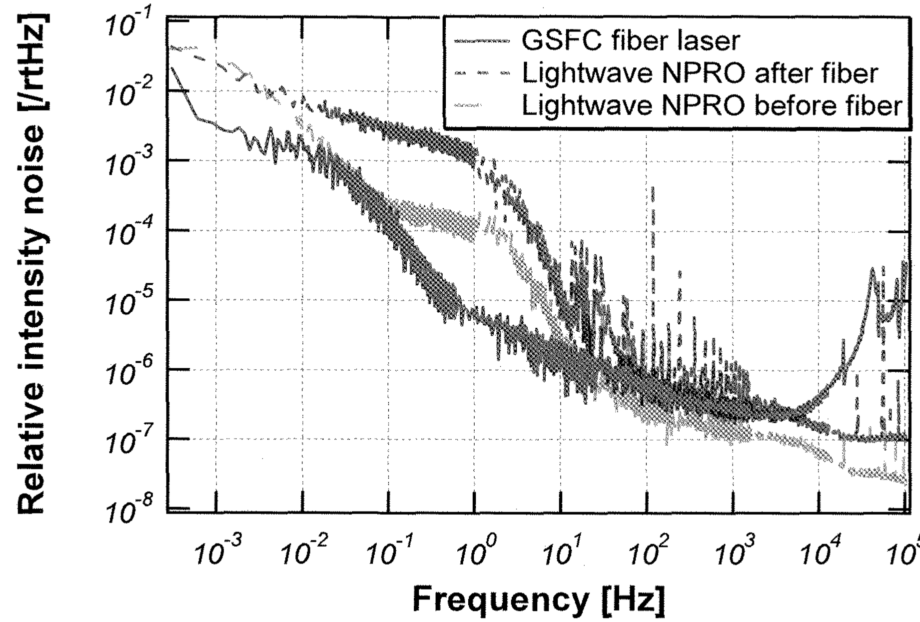


Noise performance

- Frequency noise



- Intensity noise

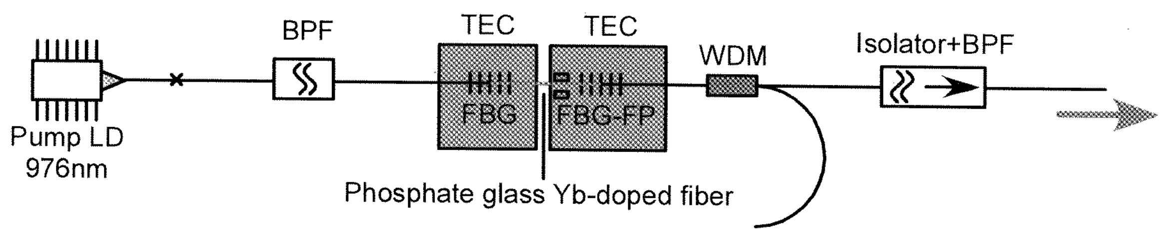


- Low frequency: comparable to (better than) NPRO
- High frequency: increased noise due to relaxation oscillation
- Stabilization experiments
  - Frequency: Planned using iodine or cavity.
  - Intensity: Done after Yb amplifier and satisfied LISA requirement at low frequency.

Fiber-DBR laser

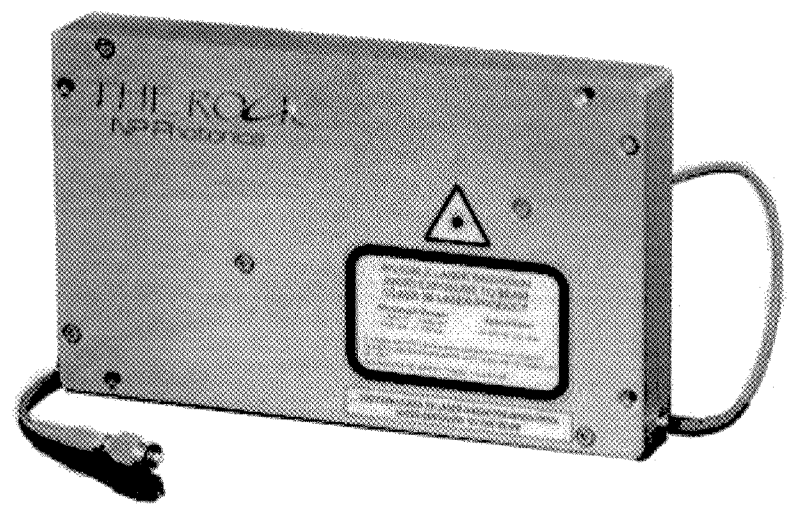
Features

- Built by NP Photonics
- Highly-doped phosphate glass fiber
  - Short cavity length
- Low reliability of splice
- Patented



Status

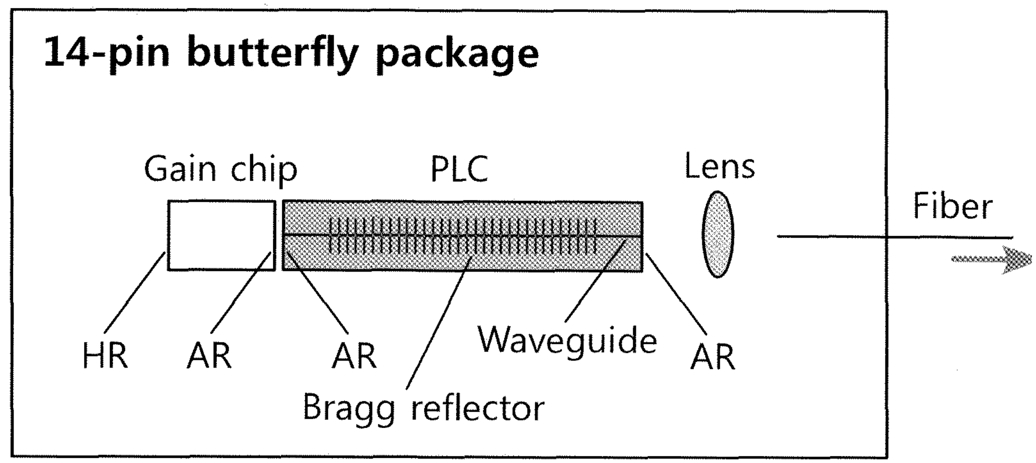
- Qualification tests by Fibertek
  - "Space version" passed thermal cycling
- Noise evaluations



External cavity diode laser

Features

- Compact & simple
- **Low cost**
  - ~$5k
- **Lowest noise** at LISA band
- Unconditionally single-mode
- Low power (~15mW)
- Telecom C-band only

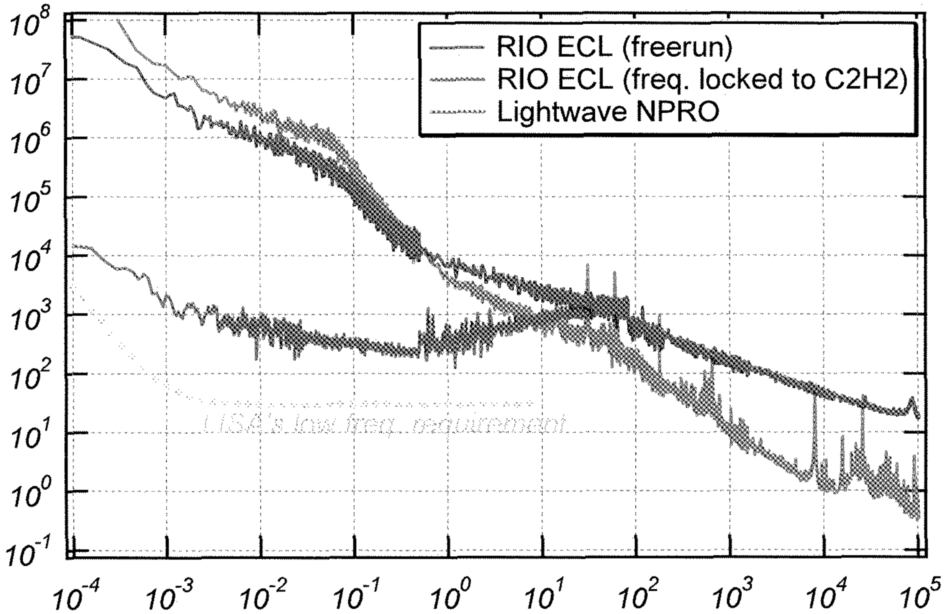


Status

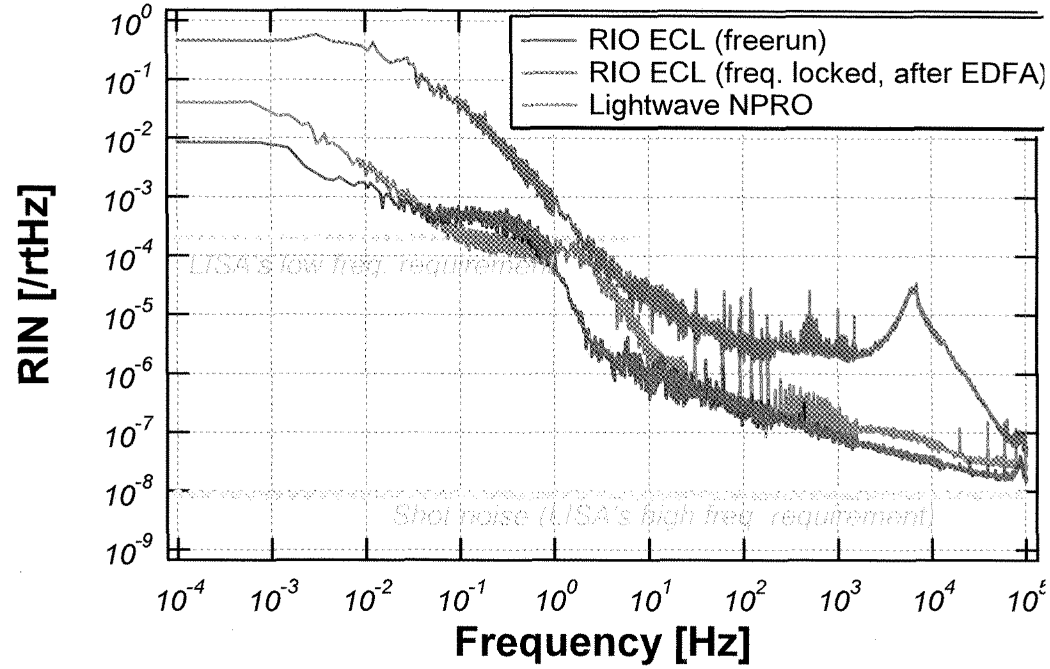
- Frequency stabilization done
- Phase locking experiment
- 1064-nm version

Noise performance

- Frequency noise



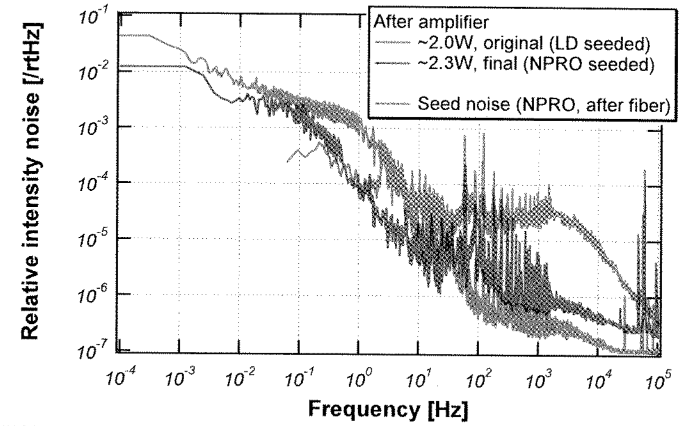
- Intensity noise

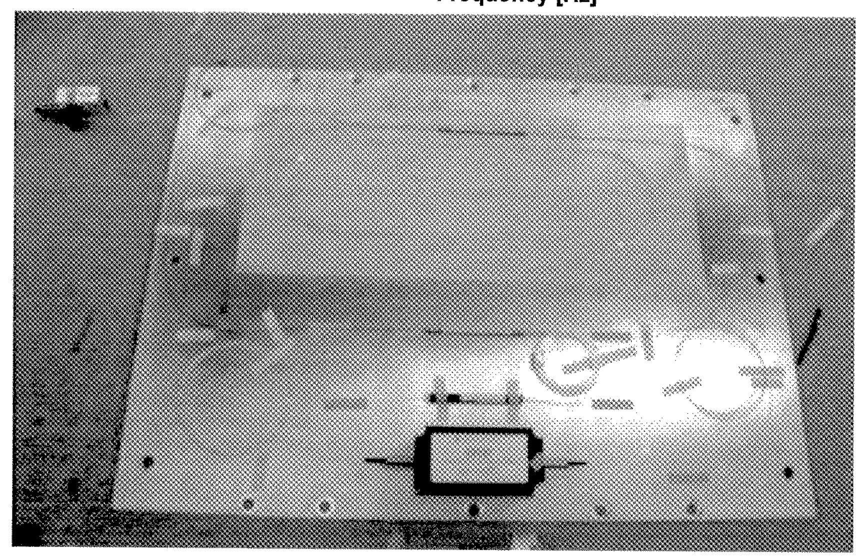


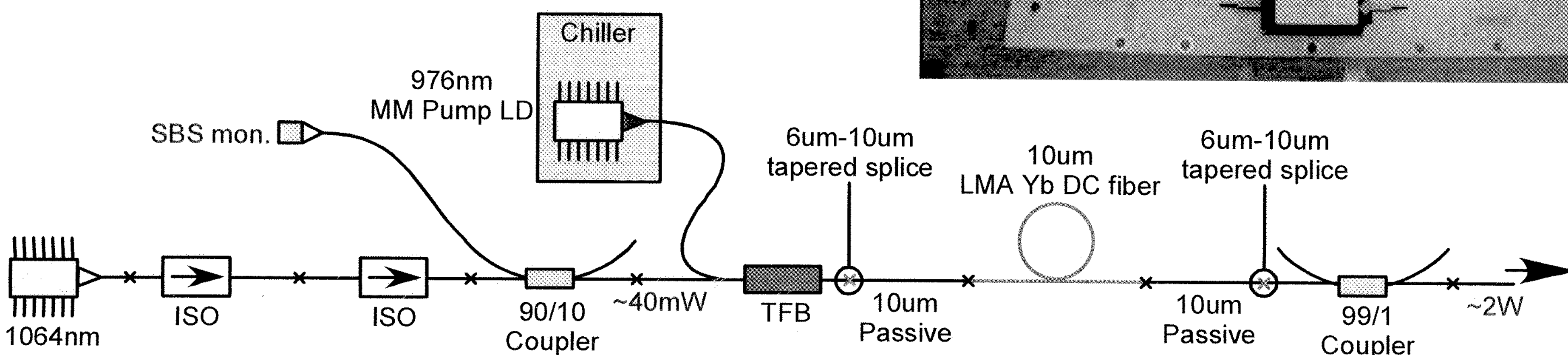
- Lowest free-running noise levels
  - Stabilization by saturation signal of acetylene at 1542nm.
  - Controllability
- High frequency noise @ high frequency
  - Under investigations

3. Fiber amplifier

- Features
  - Built by Lucent Government Solutions (LGS)
    - Clad pump, LMA fiber, ~4W maximum
  - Focused on reliability
    - Detailed risk analysis
    - Passed thermal cycling tests
- Status
  - Noise measurements at GSFC
  - Stabilization experiments



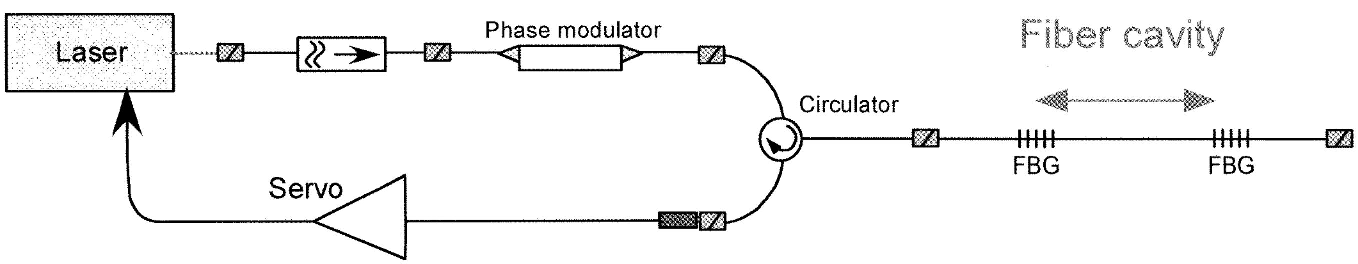


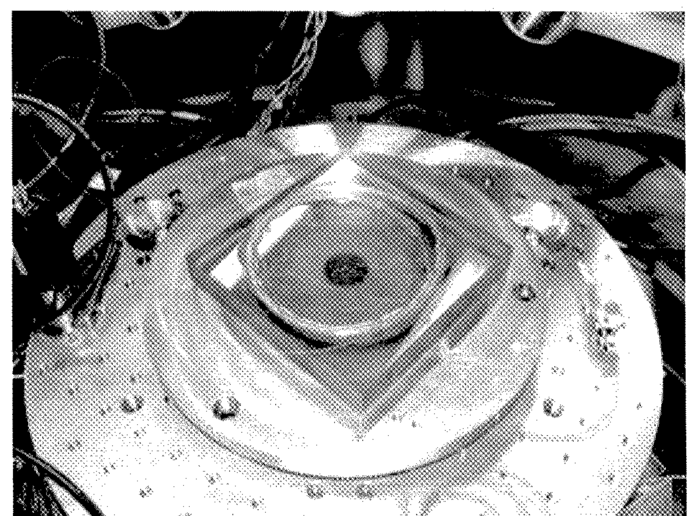


4. Other activities

- Space qualification tests
  - To be done in collaboration with LGS
    - Proton test (@ UC Davis)
    - Gamma test (@ GSFC, 7/19~)
    - Fiber components to be radiated
      - Fiber bragg grating (FBG), circulator (isolator), Band-pass filters, gain fibers, etc.
    - Outgass, pyroshock

- All-fiber frequency stabilization
  - FBG Fabry-Perot cavity
    - Finesse ~300





5. Summary

- Fiber approach very promising for space applications
  - Higher robustness, cleaner output, no strong magnet, etc.
  - Redundancy can be easily added.
  - New technology introduced frequently
  - No choice for solid-state amp for LISA-type CW, low-power applications
- Fiber-based lasers
  - At low frequency, NPRO is *not* the best anymore.
  - Custom-made fiber laser possible.
  - Possible issue is high frequency noise at higher frequency
    - Can be suppressed by fast frequency actuators (e.g. waveguide EOM)
- Current & future activities
  - Radiation tests
  - Full stabilization & metrology experiments